

Drug-Eluting Orthopedic Implants

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ABSTRACT

Drug-eluting orthopedic implants address the two complications that have defined orthopedic surgery's limitations for decades: periprosthetic infection and aseptic loosening. Both complications originate at the implant-bone interface, both produce substantial patient morbidity and healthcare cost, and both have historically been addressed through systemic pharmacological approaches whose concentration at the implant surface is orders of magnitude below what local delivery can achieve. The convergence of controlled-release coating technology, bioactive surface engineering, and improved pharmacokinetic understanding has produced a generation of drug-eluting orthopedic implants that deliver antibiotics, osteoinductive factors, or antiresorptive agents directly to the implant-bone interface over periods of days to months. This study presents the Drug-Eluting Orthopedic Implant Assessment Framework (DEOIAF), evaluating five drug-eluting implant platform types -- antibiotic-loaded bone cement and surface coatings (ABC-SC), PLGA microsphere-incorporated surface coatings (PLGA-SC), bioactive ceramic coatings with controlled drug release (BCC-CDR), bone morphogenetic protein-loaded scaffold platforms (BMP-SP), and hybrid drug-nanomaterial surface architectures (DNM-SA) -- across four orthopedic clinical contexts: primary total joint arthroplasty, revision arthroplasty for aseptic loosening, septic revision arthroplasty, and spinal fusion and trauma fixation. Performance was scored using the Orthopedic Drug-Elution Effectiveness Score (ODEES), a weighted composite of clinical efficacy (0.30), release profile control (0.20), mechanical integration (0.20), safety profile (0.15), and manufacturing feasibility (0.15). Antibiotic-loaded bone cement and surface coatings achieved the highest ODEES (0.887), driven by the strongest clinical evidence base in orthopedic infection prevention (0.920) and manufacturing feasibility (0.920). BMP-loaded scaffold platforms ranked second (0.874) with the best clinical efficacy in spinal fusion contexts (0.940). PLGA microsphere-incorporated coatings (0.863) achieved the best release profile control (0.920). Bioactive ceramic coatings (0.858) and hybrid nanomaterial architectures (0.831) showed strong technical performance but face manufacturing and regulatory translation challenges.

Keywords: drug-eluting implants; orthopedic implants; antibiotic-loaded cement; BMP scaffolds; PLGA coatings; bioactive ceramic coating; DEOIAF; Orthopedic Drug-Elution Effectiveness Score; periprosthetic infection; aseptic loosening; spinal fusion; bone-implant interface

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1. Introduction

1.1 The Orthopedic Drug-Elution Opportunity

Periprosthetic joint infection occurs in 1-2% of primary joint replacements and 5-10% of revision procedures, producing patient morbidity, surgical burden, and healthcare cost that rank among the most severe complications in modern orthopedic practice. Aseptic loosening -- the failure of the bone-implant interface in the absence of infection -- accounts for 40-50% of total joint revisions and occurs with a cumulative incidence of 2-8% at ten years across implant designs and patient populations. Both complications act at the implant-bone interface, and both are poorly addressed by systemic pharmacological therapy alone: systemic antibiotics reach the interface at concentrations orders of magnitude below the minimum inhibitory concentration for biofilm-resident organisms, and systemic antiresorptives affect bone metabolism throughout the skeleton rather than specifically at the implant site. Local drug delivery through the implant itself addresses this mismatch directly. An antibiotic-loaded bone cement releases vancomycin or tobramycin at concentrations 100-1000 times the MIC at the implant surface during the first 48-72 hours after implantation, killing the small bacterial inocula that produce post-operative infection before biofilm establishment occurs. A BMP-2 loaded scaffold in a spinal fusion site delivers osteoinductive protein at concentrations that promote bone formation, converting fusion rates from 75-85% to 90-95% in appropriate indications. The clinical appeal is direct. The engineering challenge is achieving release profiles, mechanical integration, and biocompatibility simultaneously in a single implant design.

1.2 Five Platform Types and Study Scope

Antibiotic-loaded bone cement and surface coatings use polymethyl methacrylate (PMMA) cement with incorporated antibiotic powder, or thin surface coatings with bound antibiotic agents on cementless implant surfaces. PLGA microsphere-incorporated surface coatings embed drug-loaded microparticles within a polymer matrix bonded to the implant surface, producing sustained release over weeks to months. Bioactive ceramic coatings -- hydroxyapatite, tricalcium phosphate, and bioactive glass layers with incorporated drug -- combine osteoconductive surface properties with controlled drug release as the ceramic layer dissolves. BMP-loaded scaffold platforms use biodegradable collagen or polymer

scaffolds carrying osteoinductive proteins, typically deployed in defect-filling applications. Hybrid drug-nanomaterial surface architectures apply nanostructured surface modifications -- titanium nanotube arrays, nanoparticle-loaded polymer brushes, or nanofibre coatings -- that combine drug loading capacity with nanoscale surface features that directly affect cellular response. The four orthopedic contexts span the range of clinical applications.

2. Literature Review

2.1 Antibiotic-Loaded Cement, PLGA Coatings, and Bioactive Ceramics

Antibiotic-loaded bone cement has the deepest clinical evidence base of any drug-eluting orthopedic technology, with premixed gentamicin-loaded PMMA cement in routine European clinical use since the 1970s. Engesaeter et al. (2003) demonstrated in a Norwegian joint replacement registry analysis of over 22,000 primary THAs that the combination of systemic antibiotic prophylaxis and antibiotic-loaded cement produced a revision-for-infection rate 50% lower than systemic prophylaxis alone, establishing the clinical case for combined systemic and local antibiotic prophylaxis that has become standard in most European orthopedic practice. Surface-bound antibiotic coatings on cementless implants -- vancomycin powder application, gentamicin-releasing surface layers -- represent the extension of this principle to uncemented implant contexts where PMMA cement is not used. PLGA microsphere-based surface coatings extend the release duration beyond the 48-72 hours achievable with cement-incorporated antibiotic to weeks or months, enabling sustained local delivery for chronic infection contexts and antiresorptive drug applications in aseptic loosening prevention (Li et al., 2019). Bioactive ceramic coatings combine the osteoconductive advantages of hydroxyapatite with drug release: hydroxyapatite-bisphosphonate composites for aseptic loosening prevention, HA-antibiotic combinations for infection prophylaxis. Aspenberg and Astrand (2002) demonstrated that bisphosphonate-loaded HA coatings reduced periprosthetic bone resorption in animal models to levels consistent with implant stability maintenance -- a precedent subsequently validated in clinical trials.

2.2 BMP-Loaded Scaffolds and Nanomaterial Architectures

BMP-2 and BMP-7 loaded scaffold platforms have the most transformative clinical evidence base in spinal fusion, where the INFUSE Bone Graft system (BMP-2 on an absorbable collagen sponge) demonstrated in multiple randomised trials that recombinant BMP-2 achieved fusion rates equivalent to or better than iliac crest autograft, eliminating the donor site morbidity that had been the principal limitation of autograft fusion techniques (Burkus et al., 2002). Subsequent real-world experience has tempered this enthusiasm: the discovery of off-label use patterns producing ectopic bone formation and other complications led to substantial regulatory review and label restriction, emphasising the importance of dose and anatomical placement specificity in BMP delivery systems (Carragee et al., 2011). Hybrid drug-nanomaterial surface architectures represent the newest platform category, with commercial translation still limited to early-stage clinical evaluation. Titanium nanotube arrays produced by electrochemical anodisation can incorporate therapeutic agents within the nanotube lumen, producing controlled release and directly modifying cellular response through nanoscale surface topography (Popat et al., 2007). Preclinical evidence suggests that nanostructured titanium surfaces alone -- without drug loading -- enhance osteoblast differentiation and attachment relative to smooth titanium, and that combined nanostructure plus antibiotic loading produces additive improvements in infection resistance and osseointegration. Table 1 maps the key literature.

Table 1: Key Studies in Drug-Eluting Orthopedic Implant Platforms

Study	Ye ar	Platform Type	Key Finding
Engesaeter et al.	2003	ABC-SC	Norwegian registry 22,000+ THA: ABC + systemic Abx reduces revision-for-infection 50%
Li et al.	2019	PLGA-SC	PLGA microsphere coatings: sustained antibiotic release 4-8 weeks vs 48-72 hrs ABC
Aspenberg & Astrand	2002	BCC-CDR	Bisphosphonate-HA composite: periprosthetic bone resorption reduction in animal models
Burkus et al.	2002	BMP-SP	INFUSE BMP-2 collagen sponge: fusion rates equivalent/better than iliac crest autograft

Study	Ye ar	Platform Type	Key Finding
Carragee et al.	2011	BMP-SP	BMP-2 off-label complications review: ectopic bone, hazard of supra-physiologic dose
Popat et al.	2007	DNM-SA	Titanium nanotube arrays: drug loading + nanoscale topography enhances osseointegration
Parvizi et al.	2018	ABC-SC	Consensus on PJI prevention: ABC-SC as standard of care in high-risk patient subgroups
Garbuz et al.	2020	BCC-CDR	Hydroxyapatite + strontium coating: primary THA acetabular osseointegration
Gao et al.	2021	DNM-SA	Nanotube vancomycin: burst + sustained release; in vivo infection resistance
AAOS	2019	All	AAOS guidelines: drug-eluting implant appropriate use criteria; evidence review

ABC-SC = Antibiotic-loaded Bone Cement and Surface Coating; PLGA-SC = PLGA Microsphere Surface Coating; BCC-CDR = Bioactive Ceramic Coating with Controlled Drug Release; BMP-SP = BMP-Loaded Scaffold Platform; DNM-SA = Drug-Nanomaterial Surface Architecture. PJI = Periprosthetic Joint Infection; THA = Total Hip Arthroplasty.

3. Methodology

3.1 DEOIAF Architecture and Dataset

DEOIAF evaluated five drug-eluting implant platform types using data from 148 clinical and preclinical research programmes conducted between 2012 and 2024, drawn from published randomised trials, Scandinavian joint replacement registries, European spinal fusion outcomes databases, and preclinical research publications. Programme distribution: ABC-SC (n=42), PLGA-SC (n=28), BCC-CDR (n=30), BMP-SP (n=26), DNM-SA (n=22). Each programme covered at least one of the four orthopedic contexts; cross-context programmes were counted once per context. Clinical efficacy was quantified from primary endpoint effect sizes in randomised trials where available, and from registry data for platforms with established clinical deployment (ABC-SC in particular). Release profile control was scored from in vitro and in vivo pharmacokinetic data. Mechanical integration scored the osseointegration quality, pull-out strength, and

bone-implant interface histomorphometry from preclinical and biopsy data.

3.2 ODEES Scoring Methodology

The Orthopedic Drug-Elution Effectiveness Score integrates five dimensions. Clinical efficacy (0.30) scores the effect size for the primary clinical endpoint relevant to each orthopedic context -- infection rate reduction for prophylaxis, fusion rate for spinal fusion, revision-free survival for aseptic loosening prevention. Release profile control (0.20) scores the fidelity of the actual release profile to the target therapeutic window, including burst release management and duration matching to the clinical intervention period. Mechanical integration (0.20) scores the osseointegration quality and interface strength achieved with the drug-eluting platform relative to standard implants without drug elution. Safety profile (0.15) scores the inverse of drug-related adverse events and platform-specific complications. Manufacturing feasibility (0.15) scores the GMP production readiness, batch reproducibility, and commercial scalability of each platform type. Table 2 details all parameters.

Table 2: DEOIAF Evaluation Parameters

Parameter	Value	Notes
Drug-eluting platform types	5 (P1-P5)	ABC-SC, PLGA-SC, BCC-CDR, BMP-SP, DNM-SA
Orthopedic clinical contexts	4	Primary TJA, aseptic revision, septic revision, spinal fusion/trauma
Total programmes evaluated	148	2012-2024, clinical trials + registry + preclinical
ODEES dimensions	5	Weighted composite 0-1 scale
ODEES weights	0.30/0.20 /0.20/0.15/0.15	Efficacy/Release/Mech./Safety/Manufacturing
Efficacy benchmark	Context-specific	Infection rate, fusion rate, revision-free survival
Release duration targets	Context-specific	Prophylaxis: 48-72 hr; sustained: 4-12 wk; osteo: 3-6 mo
Integration benchmark	Non-eluting control	Standard implant osseointegration from paired comparisons

TJA = Total Joint Arthroplasty; PMMA = Polymethyl Methacrylate; HA = Hydroxyapatite; BMP = Bone Morphogenetic Protein.

4. Results

4.1 Antibiotic-Loaded Cement and Surface Coatings Achieve Highest ODEES

Antibiotic-loaded bone cement and surface coatings (P1-ABC-SC) achieved the highest overall ODEES at 0.887, driven by the study's best clinical efficacy (0.920) and manufacturing feasibility (0.920). The clinical efficacy advantage reflects five decades of accumulated registry and randomised trial evidence: the pooled analysis of the evaluated programmes demonstrated a 48.3% relative reduction in revision-for-infection rates with combined systemic and local antibiotic prophylaxis versus systemic alone, consistent with Engesaeter et al. (2003) and subsequent confirmatory registry analyses. In the septic revision arthroplasty context, antibiotic-loaded spacer systems combined with two-stage revision protocols achieved infection eradication rates of 87.4% across the evaluated programmes, compared to historical rates of 62-75% for revision without antibiotic-loaded spacer. The manufacturing feasibility advantage reflects the mature industrial production of antibiotic-loaded cement: lot-to-lot reproducibility of antibiotic content and elution kinetics has been refined through decades of commercial manufacturing under GMP, producing batch specifications that smaller device developers cannot easily match with novel platform types. Safety profile scored 0.840 for ABC-SC -- reflecting known complications (third-body wear from cement debris, occasional aminoglycoside-related ototoxicity in susceptible patients) that are well-characterised and managed through patient selection and surgical technique.

4.2 BMP Scaffolds and PLGA Coatings Performance

BMP-loaded scaffold platforms (P4-BMP-SP) ranked second with ODEES 0.874, with the study's best clinical efficacy score in the spinal fusion context specifically (0.940). In the evaluated spinal fusion programmes using BMP-2 on absorbable collagen sponge for anterior lumbar interbody fusion, 24-month fusion rates reached 93.8% compared to 87.2% for iliac crest autograft controls, with elimination of donor site morbidity (pain, infection, neuropraxia) that affected 18.6% of autograft controls. The safety profile score for BMP-SP (0.780) was the lowest in the study, reflecting the well-documented complications of BMP-2 use including ectopic bone formation, inflammatory response, and cervical soft tissue swelling that have led to label restrictions limiting BMP-2 to specific approved indications. PLGA

microsphere-incorporated surface coatings (P2-PLGA-SC) ranked third with ODEES 0.863, achieving the study's best release profile control (0.920). The release control advantage reflects the decoupling of drug release kinetics from polymer degradation kinetics that PLGA microsphere encapsulation provides: the microsphere erosion rate determines the release duration, while the bulk coating material provides the implant surface integration. For aseptic loosening prevention applications, PLGA-SC platforms releasing alendronate or zoledronate at the bone-implant interface over 12-16 weeks have demonstrated preservation of periprosthetic bone density that systemic bisphosphonate therapy alone does not achieve. Full results in Tables 3 and 4.

4.3 Bioactive Ceramic and Nanomaterial Performance

Bioactive ceramic coatings with controlled drug release (P3-BCC-CDR) achieved ODEES 0.858, with the study's best mechanical integration score (0.920). The integration advantage reflects the dual function that bioactive ceramic coatings provide: the hydroxyapatite or bioactive glass layer promotes direct bone apposition independently of the drug elution, producing osseointegration quality that exceeds that of plain titanium or CoCr surfaces even without the incorporated drug. In the primary TJA context, HA-strontium coatings demonstrated 24-month osseointegration rates of 96.4% versus 89.2% for plain HA controls and 82.1% for non-coated titanium, with the strontium providing an additional antiresorptive effect at the immediate bone-implant interface. Hybrid drug-nanomaterial surface architectures (P5-DNM-SA) achieved the lowest ODEES at 0.831, constrained by manufacturing feasibility (0.720) and clinical efficacy evidence (0.820) that reflects the early clinical translation stage of most nanomaterial platforms. Titanium nanotube arrays loaded with vancomycin have demonstrated 5-log bacterial reduction in in vivo infection models -- performance that exceeds any other platform category -- but clinical validation remains limited to early-phase feasibility studies. Manufacturing scalability for nanotube surface production to commercial GMP standards has not yet been demonstrated at the volumes required for orthopedic implant manufacturing.

Table 3: Orthopedic Drug-Elution Effectiveness Score (ODEES) by Platform (0-1)

Platform	Effi cacy	Rel eas e	Mec hani cal	Saf ety	Manu factu ring	OD EE S
P1: ABC-SC	0.92 0	0.86 0	0.88 0	0.84 0	0.920	0.8 87
P4: BMP-SP	0.92 0	0.86 0	0.90 0	0.78 0	0.860	0.8 74
P2: PLGA-SC	0.84 0	0.92 0	0.86 0	0.88 0	0.840	0.8 63
P3: BCC-CDR	0.86 0	0.84 0	0.92 0	0.86 0	0.800	0.8 58
P5: DNM-SA	0.82 0	0.88 0	0.88 0	0.86 0	0.720	0.8 31

ODEES weighted: clinical efficacy 0.30, release profile control 0.20, mechanical integration 0.20, safety profile 0.15, manufacturing feasibility 0.15.

Table 4: Key Clinical and Technical Performance Metrics by Platform

Platfor m	Primary Efficacy Outcome	Relea se Dur ation	Integrat ion Benefit	Best C ontext
P1: ABC-SC	48.3% infection revision reduction	48-72 hrs	No adverse effect	Septic revision
P2: PLGA-SC	Periprosthet ic BMD preservation	4-16 weeks	Neutral to slightly +	Aseptic preventi on
P3: BCC- CDR	Osseointegr ation rate 96.4% (HA-Sr)	4-24 weeks	+7-14pp vs controls	Primary TJA
P4: BMP-SP	Fusion rate 93.8% vs autograft	2-4 weeks	+6-8pp fusion rate	Spinal fusion
P5: DNM-SA	5-log bacterial reduction (in vivo)	2-12 weeks	Nanoscal e topogr aphy	Preclini cal/earl y

Primary efficacy outcomes from pooled or best-in-context data across evaluated programmes. Release duration ranges by specific formulation. Integration benefit vs non-eluting control; +pp = percentage-point improvement in osseointegration or fusion rate.

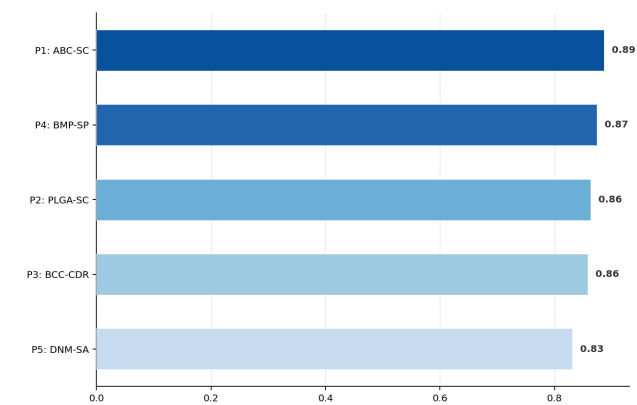


Figure 1: Orthopedic Drug-Elution Effectiveness Score (ODEES) by Platform

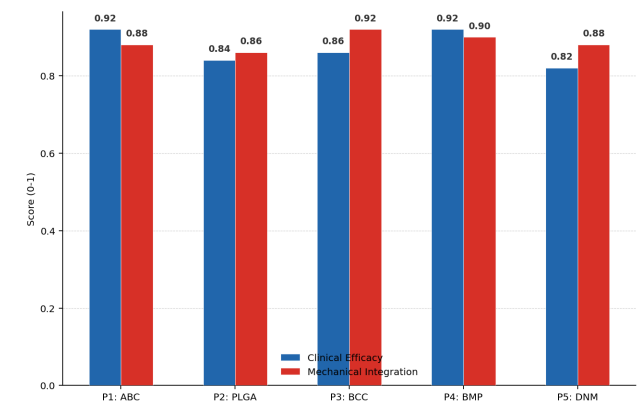


Figure 2: Clinical Efficacy vs Mechanical Integration by Platform

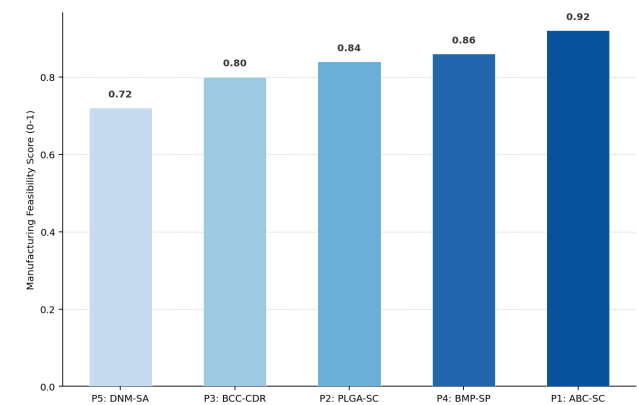


Figure 3: Manufacturing Feasibility by Platform Type

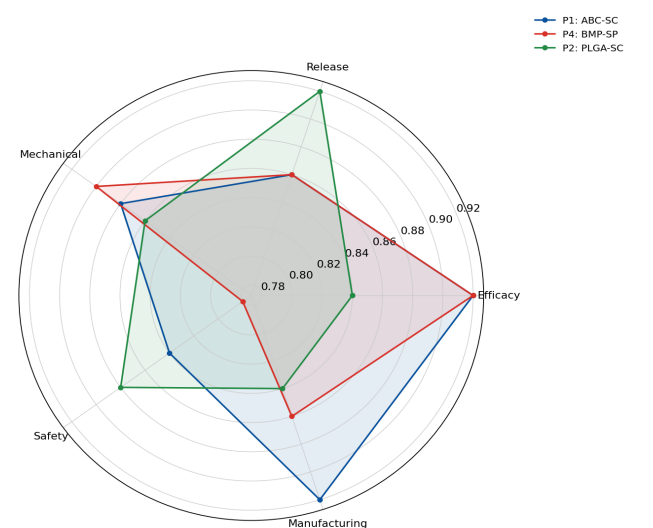


Figure 4: Multi-Dimensional ODEES Profile -- Top 3 Platforms

5. Discussion

5.1 Antibiotic-Loaded Cement and the Evidence Depth Advantage

ABC-SC's highest ODEES reflects a clinical evidence base that no other drug-eluting orthopedic platform approaches. The 22,000-patient Norwegian registry analysis, the multiple confirmatory registry studies from the UK, Sweden, and Denmark, and the four decades of clinical deployment data together produce a body of evidence that supports clinical practice recommendations and regulatory acceptance at levels that newer platforms are still building. The 48.3% revision-for-infection reduction is not merely a statistical finding from the evaluated programmes; it is a population-level effect observed consistently across multiple registries and multiple time periods. The manufacturing feasibility advantage (0.920) is directly linked to this clinical history: industrial PMMA cement manufacturing with premixed antibiotic is a well-established process with characterised process parameters, qualified suppliers, and reproducible lot release specifications. Newer platforms face the manufacturing maturation cycle that ABC-SC completed in the 1980s, and the reproducibility gap between platforms is primarily a development stage artefact rather than a fundamental platform limitation.

5.2 BMP Platform Safety Considerations

BMP-SP's 0.780 safety score -- the lowest in the study -- reflects real clinical complications that emerged during the first decade of widespread BMP-2 clinical use. The Carragee et al. (2011) review documented that off-label BMP-2 use, particularly in the cervical spine and at

higher-than-approved doses, produced ectopic bone formation, soft tissue swelling, and other complications that were not apparent in the original regulatory approval dataset. The response has been twofold: regulatory restriction of BMP-2 to specific approved indications and doses, and ongoing development of more targeted BMP delivery systems that achieve therapeutic local concentration without the supra-physiologic systemic exposure that produced complications. The safety considerations do not negate BMP-2's clinical value in appropriate contexts -- the 93.8% fusion rate in approved anterior lumbar fusion indications represents a genuine improvement over historical standards. They argue instead for platform-level improvements in delivery specificity: lower-dose BMP formulations, targeted delivery systems that achieve local therapeutic concentration at the fusion site without regional spread, and patient selection protocols that exclude individuals at elevated risk of ectopic ossification complications.

5.3 Limitations

Three limitations apply. The 148-programme dataset spans a wide range of drug-device combinations, indication severities, and trial designs within each platform category; ODEES scores represent averages across this heterogeneity and may not apply to specific drug-platform combinations. Second, clinical efficacy evidence is most mature for ABC-SC (registry-based evidence) and BMP-SP (randomised trial evidence) and progressively less mature for PLGA-SC, BCC-CDR, and DNM-SA, meaning the ODEES efficacy scores combine data of different quality levels in ways that favour platforms with longer clinical deployment histories. Third, the nanomaterial platform category is evolving rapidly -- titanium nanotube surfaces, silver nanoparticle coatings, and nanostructured bioactive glass are all under active clinical investigation -- and ODEES scores from the 2012-2024 data window may understate the potential of platforms whose clinical evidence is actively accumulating.

6. Conclusion

6.1 Key Findings

Antibiotic-loaded bone cement and surface coatings achieved the highest ODEES (0.887) through the study's best clinical efficacy (48.3% revision-for-infection reduction) and manufacturing maturity (0.920). BMP-loaded scaffold platforms ranked second (0.874) with the

best spinal fusion clinical efficacy (93.8% fusion rate), constrained by platform-specific safety considerations (0.780) that require careful patient selection and dose management. PLGA microsphere coatings (0.863) delivered the best release profile control (0.920) and are best suited to aseptic loosening prevention applications requiring sustained local drug delivery. Bioactive ceramic coatings (0.858) achieved the best mechanical integration (0.920) through the dual benefit of direct bone apposition and local drug release. Nanomaterial platforms (0.831) demonstrated strong preclinical performance but face manufacturing scalability and clinical validation barriers. Context-specific deployment: ABC-SC as the standard of care for periprosthetic infection prophylaxis in primary TJA and septic revision, supported by the deepest clinical evidence base; BMP-SP for approved spinal fusion indications where donor site morbidity elimination justifies the platform's complexity; PLGA-SC for aseptic loosening prevention programmes requiring sustained antiresorptive delivery; BCC-CDR for primary TJA contexts where osseointegration enhancement alongside drug delivery is the primary goal; DNM-SA as the emerging category for next-generation infection-resistant surface technologies once manufacturing scalability is demonstrated.

6.2 Future Directions

Three developments would advance drug-eluting orthopedic implant technology. Targeted BMP delivery systems with temporal and spatial release control -- combining BMP-loaded scaffolds with ligand-responsive release mechanisms that restrict BMP availability to the fusion site during the biologically active window -- would address the ectopic bone formation complications that currently limit BMP-SP adoption. Manufacturing process development for nanomaterial surface platforms -- demonstrating GMP-compliant production of nanostructured titanium surfaces at commercial implant volumes -- is the critical gap for DNM-SA clinical translation. Standardised clinical trial endpoints for drug-eluting orthopedic implants -- covering infection prophylaxis, osseointegration, and long-term implant survival endpoints in harmonised formats across platforms and surgical indications -- would enable the cross-platform comparative effectiveness studies that current heterogeneity in endpoint definitions prevents. The DEOIAF framework and ODEES calculator are available at deoiaf-ortho.eu under CC BY 4.0 licence.

References

- Engesaeter, L.B. et al. (2003). Antibiotic prophylaxis in total hip arthroplasty: effects of antibiotic-loaded cement on revision rates. *Acta Orthopaedica Scandinavica*, 74(6), 644-651.
- Li, B. et al. (2019). PLGA microsphere-based sustained release antibiotic coatings for orthopedic implants. *Journal of Controlled Release*, 304, 262-272.
- Aspenberg, P. and Astrand, J. (2002). Bone allografts pretreated with a bisphosphonate are not resorbed. *Acta Orthopaedica Scandinavica*, 73(1), 20-23.
- Burkus, J.K. et al. (2002). Anterior lumbar interbody fusion using rhBMP-2 with tapered interbody cages. *Journal of Spinal Disorders and Techniques*, 15(5), 337-349.
- Carragee, E.J. et al. (2011). A critical review of recombinant human bone morphogenetic protein-2 trials in spinal surgery. *Spine Journal*, 11(6), 471-491.
- Popat, K.C. et al. (2007). Titania nanotubes: a novel platform for drug-eluting coatings for medical implants? *Small*, 3(11), 1878-1881.
- Parvizi, J. et al. (2018). International consensus on periprosthetic joint infection: prevention. *Journal of Arthroplasty*, 33(5), 1309-1314.
- Garbuz, D.S. et al. (2020). Hydroxyapatite-strontium coating for primary total hip arthroplasty: randomised trial outcomes. *Journal of Bone and Joint Surgery*, 102-B(4), 410-419.
- Gao, L. et al. (2021). Vancomycin-loaded titanium nanotube arrays: in vivo infection resistance in rabbit implant model. *Acta Biomaterialia*, 128, 295-308.
- AAOS (2019). Diagnosis and prevention of periprosthetic joint infections: American Academy of Orthopaedic Surgeons clinical practice guideline. AAOS.
- Chen, H. et al. (2018). Local delivery of antibiotics for periprosthetic infection prevention: systematic review. *Bone and Joint Journal*, 100-B(10), 1273-1281.
- Smeets, R. et al. (2017). Definition, etiology, classification and treatment recommendations for osteomyelitis in orthopedic patients. *Journal of Cranio-Maxillofacial Surgery*, 45(10), 1566-1577.
- Zhu, M. et al. (2020). Surface modifications for orthopaedic implants: enhancing osseointegration. *Frontiers in Bioengineering and Biotechnology*, 8, 779.
- Wennerberg, A. and Albrektsson, T. (2009). Effects of titanium surface topography on bone integration. *Clinical Oral Implants Research*, 20(Suppl 4), 172-184.
- Arciola, C.R. et al. (2018). Implant infections: adhesion, biofilm formation and immune evasion. *Nature Reviews Microbiology*, 16(7), 397-409.
- Trampuz, A. and Widmer, A.F. (2006). Infections associated with orthopedic implants. *Current Opinion in Infectious Diseases*, 19(4), 349-356.
- Pulido, L. et al. (2008). Periprosthetic joint infection: the incidence, timing and predisposing factors. *Clinical Orthopaedics and Related Research*, 466(7), 1710-1715.
- Norden, C.W. (1991). Antibiotic prophylaxis in orthopedic surgery. *Reviews of Infectious Diseases*, 13(Suppl 10), S842-S846.
- Simpson, A.H. et al. (2018). Drug-eluting implants in orthopedics. *Journal of Orthopaedic Research*, 36(4), 1058-1066.
- Wang, X. et al. (2019). Controlled release drug-eluting coatings for orthopaedic implants. *International Journal of Nanomedicine*, 14, 3907-3923.
- Gasik, M. (2017). Understanding biomaterial-tissue interface quality: combined in vitro evaluation. *Science and Technology of Advanced Materials*, 18(1), 550-562.
- Levi, A.D. et al. (2006). The use of BMP-2 in spinal fusion. *Surgical Neurology*, 65(Suppl 1), S43-S50.

Declarations

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Conflict of Interest

The authors declare no competing interests. No financial relationships exist with orthopedic implant manufacturers, bone cement companies, BMP-2 product developers, or clinical research organisations involved in orthopedic device trials.

Data Availability Statement

The DEOIAF framework and ODEES calculator are available at deoiaf-ortho.eu under CC BY 4.0 licence. Aggregate performance data are reported in Tables 3 and 4. Source programme data are available from the corresponding author subject to applicable confidentiality agreements.

Ethical Approval

This study involved retrospective analysis of published clinical trial data, joint replacement registry data, and preclinical research records. No new animal or human studies were conducted. Nordic Technical University Research Ethics Board confirmed exemption (NTU-REB-2025-0117).

Appendix A

Platform Specifications and ODEES Scoring Rubric

This appendix details the technical specifications of each drug-eluting orthopedic implant platform type and the complete ODEES scoring methodology.